

Decomposition and Nutrient Dynamics of Litter in Long-Term Optimum Nutrition Experiments. II. Nutrient Concentrations in Decomposing *Picea abies* Needle Litter

BJÖRN BERG¹ and CARL OLOF TAMM²

¹Department of Forest Soils, P.O. Box 7001, Swedish University of Agricultural Sciences, S-750 07 Uppsala, Sweden,

²Department of Ecology and Environmental Research, P.O. Box 7072, Swedish University of Agricultural Sciences, S-750 07 Uppsala, Sweden

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Berg, B.¹ and Tamm, C. O.² (¹Department of Forest Soils, P.O. Box 7001, Swedish University of Agricultural Sciences, S-750 07 Uppsala, Sweden, and ²Department of Ecology and Environmental Research, P.O. Box 7072, Swedish University of Agricultural Sciences, S-750 07 Uppsala, Sweden). *Decomposition and nutrient dynamics of litter in long-term optimum nutrition experiments. II. Nutrient concentrations in decomposing Picea abies needle litter.* Received Febr. 2, 1991. Accepted Nov. 18, 1993. Scand. J. For. Res. 9: 99–105, 1994.

Temporal patterns of changes in nutrient dynamics were followed in decomposing *Picea abies* needle litter in a long-term optimum nutrition field experiment using N and P fertilizer. Nutrient-poor brown and nutrient-rich green needle litter were incubated in both control plots and fertilized ones.

As decomposition proceeded, we could distinguish two groups of nutrients, one for which a clear effect of fertilizer was seen (N, P, Mg) and one for which no clear effect or any clear pattern caused by the fertilizer was seen (K, Ca, Mn). Concentrations of N and P increased and were linearly related to the accumulated mass loss and their dynamics was clearly affected by the fertilizer, *viz.* the concentrations increased faster in the fertilized plot. Concentrations of Mg decreased linearly in relation to the accumulated mass loss and for the nutrient-poor brown litter the decrease rate in concentration was lower in the fertilized plot. No effect was seen of the green needle litter. For Ca the concentration increased initially in all four cases but then decreased. Concentrations of K decreased initially in all four cases and then remained largely constant. The concentration of Mn increased in all four cases but no significant difference could be seen either between control plot and fertilized plot, or between litter types. *Key words:* calcium, decomposition, fertilization, magnesium, manganese, Norway spruce, nitrogen, nutrient uptake, nutrient release, phosphorus, potassium.

INTRODUCTION

The low decomposition rate of litter in many coniferous forests has been ascribed to acid soils, a harsh climate, and to the tendency for such litter to be poor in mineral nutrients but rich in lignin (Flanagan & Van Cleve 1983). In undisturbed forest sites this will lead to an accumulation of organic matter in the forest floor, and the storage of essential plant nutrients, especially N, thereby leading to a final reduction in tree growth (Hesselman 1937, Tamm & Carbonnier 1961).

Of the factors that influence the turnover rate of the forest-floor material—and consequently, also the rate of nutrient release—the chemical composition of the added tree litter has received some attention. In some studies, the N concentration in the substrate was concluded to be the factor limiting the rate of litter decomposition (Melin 1932, Edmonds 1980). Berg & Staaf (1980) described a two-phase decomposition

model in which higher initial concentrations of N, P, and S enhanced litter mass loss in early stages. In later stages the elevated lignin concentration strongly retarded mass-loss rates. The degree of retardation was largely similar irrespective of the litter's nutrient contents. When using leaf litters with a wider range of nutrient concentrations, Berg & Ekbohm (1991) found that the decomposition rates of lignin and of litter in late stages were inversely related to N concentrations.

Patterns of change in nutrient concentrations vary, depending on the type of nutrient (Staaf & Berg 1982). Nitrogen (*cf.* Berg & Staaf 1981) as well as P (*cf.* Berg & McClaugherty 1989) appear to have relatively predictable dynamics. By contrast, the dynamics of Mg, K and Mn so far have not been given any clear pattern. As decomposition proceeds, concentrations of N, P and S tend to increase linearly in relation to accumulated mass loss. In highly decomposed litter a concentration decrease may occur as

has been reported for red pine (R. Boone, pers. comm.) and grey alder leaf litter (B. Berg & J. Cortina, unpubl.). Nutrients that are highly mobile, like K and Mn, and not limiting for microorganisms, tend to decrease in concentration (Staaf & Berg 1982).

In view of the frequent use of N fertilizer in forests, the effects of fertilization on the chemical composition and the decomposition of litter should be of considerable silvicultural interest, since N-fertilized trees produce a litter enriched in N and P, among other nutrients (Miller & Miller 1976, Berg & Staaf 1980). The concentration of a nutrient such as N in litter might enhance the mass-loss rate initially, but delays decomposition in latter stages, two phenomena that influence the dynamics of the soil organic matter as well as nutrient release.

In this study, we have investigated the decomposition dynamics of Norway spruce needle litter from stands given different doses of N and P fertilizer. Our aims were to determine; (i) the influence of litter chemical composition on the nutrient concentrations changes and, (ii) the influence of fertilizer on the concentration changes in decomposing litter.

In an earlier study, Berg & Tamm (1991 *b*) presented data on the initial chemical composition of falling litter as well as a study on lignin influence on litter mass-loss rate of the same litter in the same optimum-nutrition experiment. A later article will present net changes in amounts of nutrients during decomposition.

MATERIALS AND METHODS

Site description

The optimum-nutrition experiment was established at Stråsan, Central Sweden (60°55' N; 16°01' E), on a till soil. The site is located on a partly steep west-facing slope, at a mean altitude of 350 m. The annual mean temperature is 3.4 °C (Vedin 1973), and the annual precipitation 775 mm (Eriksson 1980). The average AET is 422 mm (Eriksson 1980).

The area was planted with Norway spruce (*Picea abies* (L.) Karst.) in 1957 and for the fertilization experiment, which was started in 1967, the area was divided into 30 m × 30 m plots. A detailed description of the experiment is given by Tamm et al. (1974).

Fertilizer was added once annually, with the dosages given in Table 1. Solid fertilizer was spread out by hand (ammonium nitrate and superphosphate). During the course of the decomposition ex-

Table 1. *Dosages of fertilizer (N, P, K, Mg and Ca) applied to plot No. 4 denominated N2P2KMgMicro in the optimum nutrition experiment at site Stråsan*

No fertilizer was applied to control plot (N0). Dosage is given for N, P, K, Mg and Ca additions. For information on dosages of micro nutrients the reader is referred to the full table given by Tamm (1991). A dash indicated no addition

Year	Dosage applied, kg ha ⁻¹ yr ⁻¹				
	N	P	K	Mg	Ca
1967	120	40	80	22	4 000
1968	120	—	—	—	—
1969	120	40	80	22	—
1970	80	20	—	—	—
1971	80	—	—	—	—
1972	80	—	—	—	—
1973	80	—	—	—	—
1974	80	40	80	22	—
1975	80	—	—	—	—
1976	80	—	—	—	—
1977	60	40	80	22	—
1978	60	—	—	—	—
1979	60	—	—	—	—
1980	60	40	80	22	—
1981	60	—	—	—	—
1982	60	—	—	—	—
1983	60	—	—	—	—
1984	60	40	80	22	—
1985	60	—	—	—	—
1986	60	—	—	—	—

periment, fertilizer was spread out in early May in each of the years 1982, 1983, 1984, 1985 and 1986. In early May, 1984, K, Mg, Mn, B, Zn, Cu and Mo were added as well.

Decomposition experiment

Needle collection, sample preparation, incubation and sampling has been described by Berg & Tamm (1991 *a, b*) who also described mass-loss rates and changes in lignin concentrations during decomposition. In the present study, net nutrient dynamics was studied in two plots only, viz. plot 13 (N0, control) plot and plot 4 (N2P2KMgMicro) fertilized with N and P (N2P2). In each plot, the nutrient dynamics of brown and green needle litter, both collected in a control plot, were followed. In the present study, one incubation of litter was made. Samplings were made 3–4 times annually. At each sampling one litter bag of each type from each of 25 spots was taken.

The 25 replicates from each sampling were combined and ground in a laboratory mill equipped with

a 1 mm screen. The milled samples were analyzed to determine their total contents of N, P, K, Ca, Mg and Mn. Ash content was only determined on some of the initial samples.

Nitrogen content was determined in an elemental analysis by combustion (Elemental Analyzer NA 1500; Carlo Erba, Strumentazione 20090 Rodano, Milan, Italy). To determine contents of P, Mg, K, Ca and Mn, samples were digested for 2 days in a 2.5 : 1 (v/v) mixture of nitric and perchloric acid. The analyses were performed by plasma atomic emission spectrometry ICP-AES (Jobin YVON JY-70 Plus 16–18, rue du Canal 91163, Longjumeau, France). Ash concentration was determined by combustion at 550 °C for 2 h.

All data on mass loss and chemical changes are stored in two reports (Berg et al. 1986, Berg & Tamm 1991 a).

RESULTS

Changes in nutrient concentrations during decomposition

In the present experiment we studied the decomposition of brown and green needle litter, with chemically identical litter incubated in both the control and the fertilized plots. Thus it was possible to compare the dynamics of each nutrient in a very straightforward manner.

Changes in concentrations of N, P, Mg, Ca, K and Mn during decomposition were related to accumulated litter mass loss (Figs. 1, 2). The patterns of concentration changes varied considerably between the nutrients. For cases in which an initial loss of some nutrients had taken place before a more regular loss pattern became established, we concluded that leaching had occurred. Thus, when calculating regression lines, the first point, giving the initial concentration, was omitted for P, K and Mn. Once leaching had ceased, a clear increase in concentration took place.

For three nutrients (N, P and Mg) it appeared reasonable to accept linear models for concentration changes (Fig. 1, Table 2). Concentrations of N and P increased about linearly with accumulated mass loss in both brown and green litter, of which the latter was more nutrient-rich (Table 2, Fig. 1). To compare relative rates of concentration increases we used the slope coefficient; high coefficient values reflect high increase rates and vice versa. In contrast to the behaviour of these nutrients, the concen-

tration of Mg decreased linearly with accumulated mass loss.

The slopes of the regression lines relating N concentrations to accumulated mass loss in brown needles were 0.1393 mg %⁻¹ for the N0 plot and 0.2073 mg %⁻¹ for the N2P2 plot (Table 2) and were significantly different (Fig. 1). For the green needles the pattern was similar. The slopes for N concentration increase rate in green needles were 0.2894 mg %⁻¹ and 0.3858 mg %⁻¹ in the N0 and N2P2 plots, respectively (Table 2), the difference being significant (Fig. 1). Thus, in both cases the slopes were steeper in the litter incubated in the fertilized plot.

The rate of increase in N concentration with accumulated mass loss was higher for the initially more N-rich green needles than for the brown ones (Fig. 1), an observation seen in both the N0 and the N2P2 plots (Table 2).

The relationships between P concentration and accumulated mass loss were very similar to those of N (Fig. 1). Thus, P concentration increase in brown needle litter had a slope of 0.00642 mg %⁻¹ (Table 2) in the N0 plot, and 0.0151 mg %⁻¹ in the N2P2 plot which makes it about twice as steep. For green needles, which were initially richer in P, the slopes were 0.00668 mg %⁻¹ and 0.01465 mg %⁻¹, respectively, in the N0 and N2P2 plots. Thus, for both litter types, the rate of increase was about twice as high in the N2P2 plot, and the differences between plots were statistically significant (Fig. 1). In contrast to the slopes for N, no difference was observed between slopes for the two litter types when incubated in N0 or N2P2 plots (Table 2).

The concentration of Mg decreased linearly with accumulated mass loss for both litter types and in both the N0 and N2P2 plots (Fig. 1) and the relationships were statistically significant in all four cases. However, for the brown needle litter the decrease in concentration occurred more than twice as fast in the N0 plot (–0.00992 mg %⁻¹) than in the N2P2 plot (–0.00384 mg %⁻¹) (Table 2) and the difference was statistically significant (Fig. 1). For the green needle litter, there was no difference between treatments, possibly because this litter type had such a high Mg concentration that any uptake by microorganisms was too small to affect the net outflow (Fig. 1).

The change in Ca concentrations was not linearly related to accumulated mass loss (Fig. 2). In all four cases, there was an initial drop in concentration, possibly due to leaching; thereafter concentrations rose sharply and then decreased strongly again. The

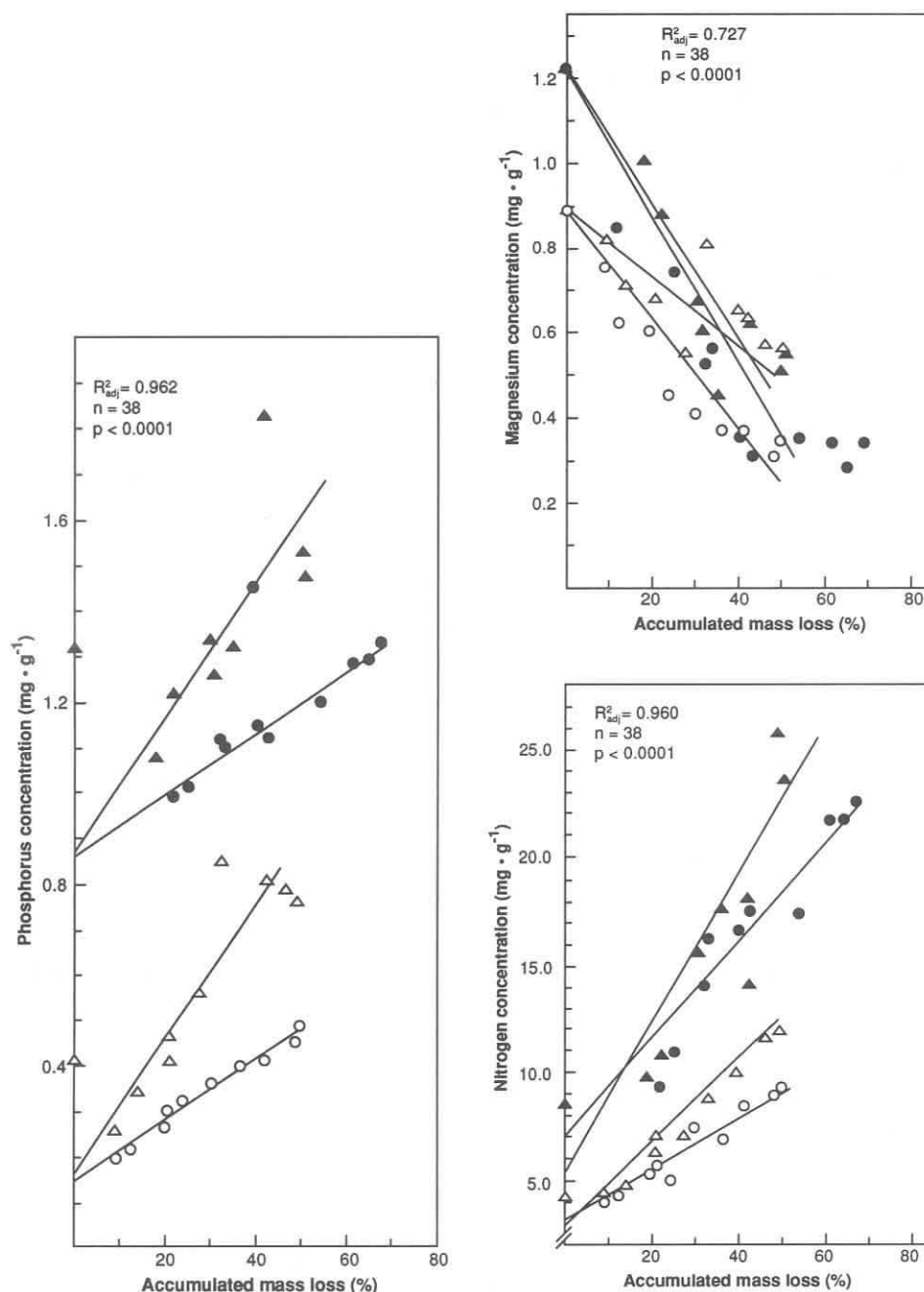


Fig. 1. Linear relations for concentrations of N, P and Mg in comparison with accumulated mass loss in decomposing Norway spruce needle litter. Brown needle litter ($\circ$) and green needle litter ($\bullet$) incubated in a control plot (No. 13). Brown needle litter ($\triangle$) and green needle litter ($\blacktriangle$) in a fertilized (N2P2MgKMicro, No. 4) plot.

pattern of fluctuations was very similar for both types of litter and for both types of plots. Four clear peaks in concentration could be seen in each of the brown and green litters. Moreover, there was a high level of coincidence of concentration peaks between fertilized and unfertilized plots.

The pattern of change in K concentrations varied, depending on the litter type and plot (Fig. 2). In the

brown litter, there was an initial quick decrease due to leaching, in which the concentration decreased from initially 1.04 mg g^{-1} to 0.4 mg g^{-1} . After the leaching there was a weak, but statistically significant, increase in the brown litter incubated in the control plot, whereas in the fertilized one, no clear change in concentration was seen after the initial leaching (Fig. 2). In the green needles, there was a sharp drop in

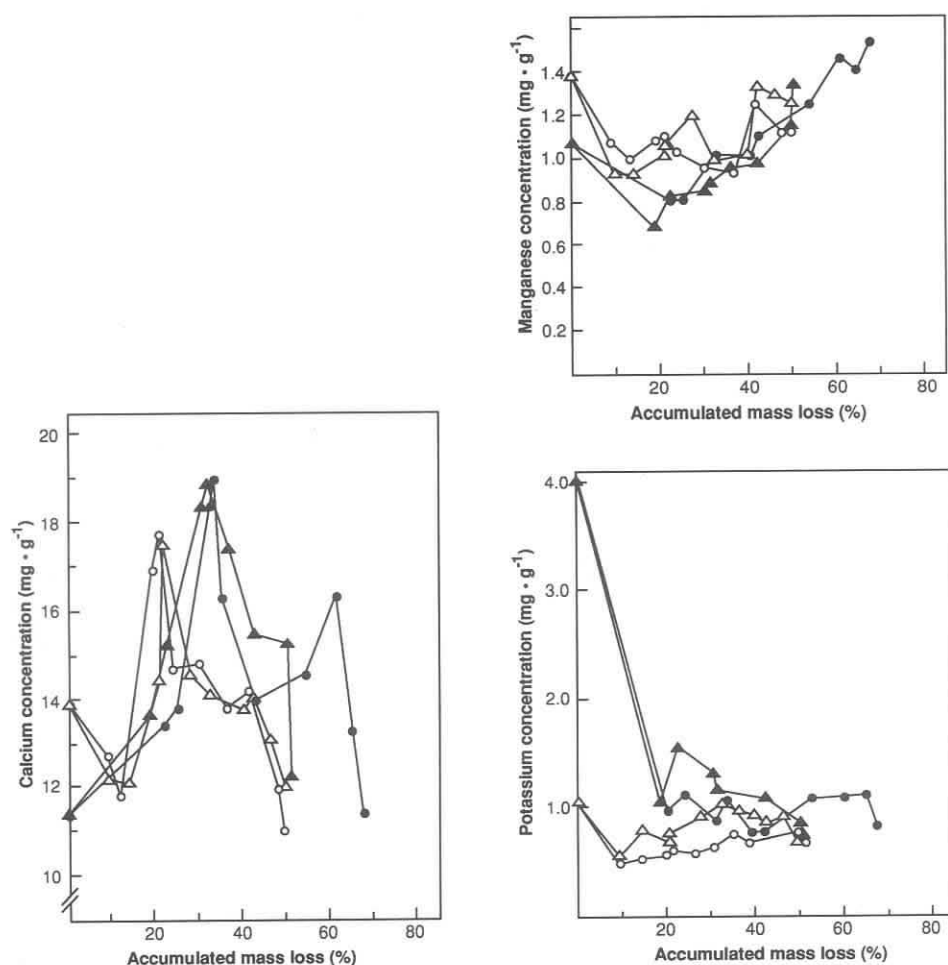


Fig. 2. Scatter plots for the concentration for Ca, K and Mn plotted versus accumulated mass loss in decomposing Norway spruce needle litter. Denominations as in Fig. 1.

Table 2. Slopes of the regression lines relating nutrient concentrations to accumulated mass loss for decomposing brown and green needle litter of Norway spruce

Brown and green needle litter originated from control plots and were incubated in control and fertilized plots. Levels of significance are indicated: $p < 0.0001$ (***) and $p < 0.05$ (*)

Nutrient	Rate of change in concentration, $\text{mg } \%^{-1}$ ($\pm$ S.E.)			
	Brown needle litter		Green needle litter	
	N0 plot	N2P2KMgMicro plot	N0 plot	N2P2KMgMicro plot
Nitrogen	0.1393*** (0.0113)	0.2073*** (0.024)	0.2894*** (0.0228)	0.3858*** (0.0487)
Phosphorus	0.00642*** (0.0004)	0.01506*** (0.0024)	0.00668*** (0.0005)	0.01465* (0.00518)
Magnesium	-0.00992*** (0.0012)	-0.00384* (0.0020)	-0.01465*** (0.002)	-0.00949* (0.00374)

concentration due to leaching (from 4.0 mg g^{-1} to about 1 mg g^{-1}), after which the concentration remained about constant for the duration of the experiment. No difference was seen between the control plot and the fertilized one.

In both the brown and green needle litters in the N0 and N2P2 plots there was an initial period of leaching of Mn that resulted in a quick drop in concentration. Thereafter, the concentration increased steadily (Fig. 2). For both litter types there

was a statistically significant increase in concentration in relation to accumulated mass loss in both plots. For the green needle litter the slope for concentration increase appeared to be steeper than that for the brown litter, but no difference was seen between litter in the fertilized plot as compared to the control plot.

DISCUSSION

The patterns for concentration changes differed between the nutrients. For N and P, increases in concentration linear to accumulated mass loss have been observed in all cases reported (cf. Berg & McClaugherty 1989) for newly fallen litter.

The slope for N increase was steeper for green needles than for the brown ones, both in the N0 and the N2P2 plots. The reason for this is not known. Similar findings were obtained in an earlier study using Scots pine needle litter with a wide range of initial N concentrations (B. Berg, unpubl.). B. Berg & J. Cortina (unpubl.) observed a tendency for the N concentrations to increase at a higher rate at higher initial concentrations. Over a climatic region and for litter incubated on different soil types the slopes for increase rates of N concentrations were found to be very similar, though (B. Berg & M.-B. Johansson, unpubl.). In the present study, we observed that the increase rate for N concentration in litter was higher in the fertilized plot, an observation that has not earlier been reported. This indicates a stronger uptake rate by decomposing microorganisms, which may have a more easily available supply of N.

Magnesium concentrations were found to decrease linearly with accumulated mass loss. Also Staaf & Berg (1982) found this for Scots pine needle litter but the relationship observed by them was positively linear. The initial concentration in their litter type was low, though (about 0.38 mg g^{-1}) in comparison with the concentrations in the present study (0.9 and 1.22 mg g^{-1}). It is, thus, possible that there is an optimum concentration for the decomposing microorganisms and that there may be an equilibrium concentration of Mg between 0.38 and 0.9 mg g^{-1} at which no concentration change would take place during the decomposition process. Similar observations have been made for N (Berg et al. 1987) and for K (R. Laskowski, B. Berg, M. Johansson & C. McClaugherty, unpubl.).

Calcium concentrations increased to a maximum followed by a decrease. This pattern has also been found both in decomposing Scots pine (Staaf & Berg

1982) and decomposing Lodgepole pine needle litter (B. Berg unpubl.). Four clear peaks in concentration could be seen in each of the brown and green litters. Moreover, there was a high level of coincidence of peaks between fertilized and unfertilized plots. This suggests that N and P fertilizer did not influence the Ca dynamics in the decomposing spruce needle litter.

The patterns for K and Mn suggest that there was no effect of fertilizer on the concentration changes for these nutrients. The heavy drop in concentration in the green needle litter suggests that a large part of the K was in a highly mobile form but that a considerable part was also bound to the non-soluble fraction of the litter.

We may reach the following conclusions;

1. the clear difference in the dynamics of N and P in the decomposing needle litter between the fertilized plot and the control plot will have consequences for the composition of humus and the pools of more stabilized forms of these nutrients.
2. in the fertilized plot the litter in humus-near stages tended to be richer in N and P than the corresponding litter in the control plot. The nutrient-rich green needle litter was so much richer in N and P than brown needle litter that a humus formed from green litter would be more nutrient-rich than that of brown litter from a heavily fertilized stand.
3. for K and Mn, the addition of fertilizer did very little to the concentration of these components in late stages of decomposition, suggesting that these nutrients were in excess and that the retaining mechanisms were saturated.

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